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*Editors*

# Current Trends in Eye Tracking Research

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# Introduction

Eye tracking research and research methodologies are becomingly increasingly common in many disciplines from psychology and marketing to education and learning. This is because eye tracking research and research methodologies offer new ways of collecting data, framing research questions, and thinking about how we view, see, and experience the world. Researchers are also making new findings about the way that the visual system works and the way it interacts with attention, cognition, and behaviour.

As a result, research based on eye tracking research methods is increasing in every discipline. New studies using eye tracking technologies are continually being published and new applications of this innovative way of conducting research are being shared by researchers from every continent and country. Analysis of research using eye tracking methods is growing exponentially.

*Current Trends in Eye Tracking Research* presents a range of new research studies using eye tracking research and research methods from a wide variety of disciplines. The research studies have been chosen to chronicle the wide applications and uses of eye tracking research.

*Current Trends in Eye Tracking Research* is comprised of new and innovative studies using eye tracking research and research methods and showcases innovative ways of applying eye tracking technologies to interesting research problems. The book collects the research of over 55 researchers and academics currently using the eye tracking research and introduces the work of a number of eye tracking research laboratories and their key staff and research interests.

*Current Trends in Eye Tracking Research* is designed to explore a broad range of applications of this emerging and evolving research technology and to open the research space for wider sharing of new research methods and research questions. The book incorporates a number of new studies and introduces a number of new researchers to the practitioners of eye tracking research.

*Current Trends in Eye Tracking Research* also focuses on lessons learned in conducting eye movement research across multiple institutions, settings, and disciplines and innovative uses of existing technology as well as pioneering implementation of new technology in a range of research contexts and disciplines, key challenges, and important discoveries in moving from raw data to findings and challenges and opportunities related to situating individual research efforts in a larger research context.



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*Current Trends in Eye Tracking Research* is divided into four key sections. Each section provides a central theme that integrates the many chapters in that section.

Part I is titled *Eye Tracking and the Visual System* and is concerned with research on the operation of the human visual system. The chapters in this section overview eye tracking and the human visual system research, and provide a series of chapters that examine how to explain the operation of the human visual system and fundamental research on the use of eye tracking to deepen and strengthen our understanding of the complexity of visual processes.

Part II is titled *Aligning Eye Tracking and EEG Data* and is concerned with research that reports on the alignment of EGG and eye tracking data. The chapters in this section overview fundamental research finding on how to link eye tracking and EEG data. The chapters in this section also address some critical research questions in integrating eye tracking data with other forms of data. The four chapters also overview current approaches to research on this alignment process.

Part III is titled *Eye Tracking and Marketing and Social Applications* and is concerned with eye tracking based research in a range of social science and marketing disciplines. Each chapter provides a different application from a different discipline—from marketing to aging, from mental illness to evaluating forgeries to understanding what people see when they read financial reports. Each chapter provides a novel application of eye tracking research methodology in the social sciences.

Part IV is titled *Eye Tracking and Education* and is concerned with research on learning using eye tracking methodologies. The five chapters focus on fundamental research problems in learning such as reading comprehension and the visual mechanics of comprehension, learning to read complex visual displays, and the development of student self-regulation skills. The section also explores the use of think aloud research protocols for multilingual learners.

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# Contents

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# Part I
# Eye Tracking and the Visual System

# The Active Eye: Perspectives on Eye Movement Research

**Benjamin W. Tatler, Clare Kirtley, Ross G. Macdonald, Katy M. A. Mitchell and Steven W. Savage**

Many of the behaviours that humans engage in require visual information for their successful completion. In order to acquire this visual information, we point our high-resolution foveae at those locations from which information is required. The foveae are relocated to new locations around three times every second. Eye movements, therefore, offer crucial insights into understanding human behaviour for two reasons. First, the locations selected for fixation provide us with insights into the changing moment-to-moment information requirements for the behaviours we engage in. Second, despite the fact that our eyes move, on average, three or four times per second, we are unaware of this and most of the time we are not conscious of where we are pointing our eyes. Thus, eye movements provide an ideal and powerful objective measure of ongoing cognitive processes and information requirements during behaviour. The utility of eye movements for understanding aspects of human behaviour is now recognised in a wide diversity of research disciplines. Indeed, the prevalence, diversity and utility of eye movements as research tools are evident from the contributions to be found in this volume.

In this brief overview, we take a glimpse at some of the emerging areas of study in eye movement research. To do so comprehensively and in a manner that reflects the impressive breadth of work contained in this volume would be a task that is both beyond the expertise of the authors and beyond the length of the chapter that we have been asked to write. Instead, we choose to introduce some emerging areas (with a clear bias towards our own research interests) that we feel will play an increasingly important role in shaping the direction that eye movement research will take over the coming years. A number of articles have reviewed eye movement research from particular perspectives and we refer the reader to several key reviews of eye movement research. Kowler (2011) provides a review of a wide variety of findings in eye movement research over the last 25 years or so. For a review of the link between eye movements and perception, see Schutz et al. (2011). Eckstein (2011) discusses contemporary and historical views on visual search and the roles that eye movements play in this process. While slightly earlier than the other reviews,

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Rayner (1998) offers an important overview of eye movements in reading. In this chapter, we focus upon the link between eye movements, perception and action.

## 1 Perception in Action

When we perceive our environment, we are acting in order to gain information that will help us perform the tasks in which we engage. In this way, perception is not simply the passive reception of information from our surroundings, but is an active part of how we operate in the world. This view is increasingly prominent in cognitive psychology (e.g. Hommel et al. 2001; Bridgeman and Tseng 2011). Indeed, Hommel et al. (2001) suggested that perception and action are 'functionally equivalent', with both processes working to allow us to build representations of the world around us. Perception and action processes appear to be linked in a bidirectional manner, so that each is able to affect the other: While perception informs the performance of action, action influences perceptual processes.

With this more active role for perception proposed, the question then is how to measure it. This is perhaps more difficult; as Bridgeman and Tseng (2011) state: Most effectors, such as the hands, double as tools for both action and perception. This is where eye movements become an invaluable tool: Eyes select and sample visual information and, thus, provide an online measure of perception, yet do not act directly upon the environment. Eye movements are an important means of investigating perception and action because they are perception in action, directed by the task to examine the world and allow us to complete the tasks set for us.

The importance of eye movements for coordinating perception and action can be seen clearly in the many studies that have made use of them. The eyes have two crucial functions: first, to gather information about the world and, second, to provide feedback during tasks, for example, when we manipulate an object. Using eye movements, these processes can be measured online as tasks are performed in both laboratory and real-world environments. For example, in the laboratory, Ballard et al. (1992) used a block-copying task in which participants moved a series of coloured squares from one location to a target area and arranged them to match a model depicting an arrangement of blocks that they had to recreate. The eye movements of the participants as they did this were shown to link strongly to the actions they were carrying out. The eyes followed a clear pattern of checking the model, preceding the hands to the blocks for the pick-up, then checking the model once more before placing the block in its correct position.

Ultimately, if we wish to understand the link between perception and action, we must do so in the context of natural behaviours conducted in real world environments. Mobile eye-tracking devices permit eye movement recordings to be made in untethered, real-world activities. This technological advancement has not only allowed researchers to study eye movements in the context of natural action but has also identified key insights into the relationship between vision and action that were not previously recognised. Mobile systems were developed in the 1950s by

Norman Mackworth and used in real environments in the 1960s (e.g. Mackworth and Thomas 1962; Thomas 1968). These devices were cumbersome and it was not until the 1990s that less obtrusive and more versatile mobile eye trackers were developed (Ballard et al. 1995; Land 1992). Using such devices, the tight link between vision and action is strikingly clear in real-world activities. Land et al. (1999) and Hayhoe (2000) measured participants' eye movements as they went through the stages of making a cup of tea or preparing a sandwich. Again, the findings demonstrated how vision acts to inform our behaviour: Throughout the constantly changing demands of the task, the participant's eyes precede the actions, fixating the required objects for the next step in the process. Furthermore, Hayhoe (2000) showed that when making a sandwich, the action intention could influence the deployment of attention. Participants were seated in front of either a non-cluttered tabletop, containing only the items needed for the sandwich-making task, or a busier tabletop, containing irrelevant objects along with the important ones. While these irrelevant objects were fixated, the greatest percentage of fixations came in the viewing period before the task began. Once the participants had started, task-irrelevant objects were rarely fixated: Almost all fixations were made to task-relevant items.

These examples illustrate the intimate link between vision and action and the manner in which eyes are deployed on a moment-to-moment basis to gather information and provide feedback for actions. The bidirectional nature of the perception–action coupling is evident in tasks where perceptual decisions are made in the presence of action. Indeed, before an action has begun, the intention to carry out an action influences how participants view a scene, even when the intention is created by a seemingly minor manipulation such as the performance of a particular grip type. For example, Bekkering and Neggers (2002) asked participants to find targets based on colour or orientation, in order to grasp or point at them. For orientation-defined targets, when participants searched to grasp the object, they made fewer incorrect saccades to the distracter objects compared to the situation when targets were defined by colour. This difference between colour- and orientation-based search was absent when participants were searching only to point to the object rather than grasp. The preparation of the grasp led to enhanced processing of the relevant feature for the action, in this case the objects' orientation, and, thus, detection of targets defined by that feature was enhanced. Similarly, Fagioli et al. (2007) asked participants to prepare different types of gestures, such as pointing or grasping. Before they could carry out these prepared actions, participants were given a detection task, which required them to find the odd one out in a set of objects. This target was defined by either its location or its orientation. Preparing a pointing gesture resulted in participants spotting the location oddity sooner, while the orientation oddity was spotted soonest when a grasping gesture was prepared. Thus, even when the action prepared did not directly relate to the following task, the enhanced processing of relevant dimensions was continued. Symes et al. (2008) used this action–preparation paradigm in a different task setting to look at change detection. Here, power and precision grip types were formed by participants during change blindness trials, and it was demonstrated that change detection improved for objects whose size matched the grip type held by the participant.

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